Next Generation Satellite Systems For Aeronautical Communications: Research Issues

NATIONAL CENTER OF EXCELLENCE FOR
NEXTOR
AVIATION OPERATIONS RESEARCH

NEXTOR, *National Center of Excellence for Aviation Operations Research*

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Research Results

I: Developed traffic and application scenarios for the year 2020
- Calculated for various decision-making modes: (tactical, near-term strategic, far-term strategic)

II: Developed hybrid uni-cast/broadcast satellite communications model:
- Using results from (I) calculated bandwidth requirements under various assumptions
- Explored sensitivity of system costs to various assumptions; found best architecture under various conditions

Three Regions of Interest

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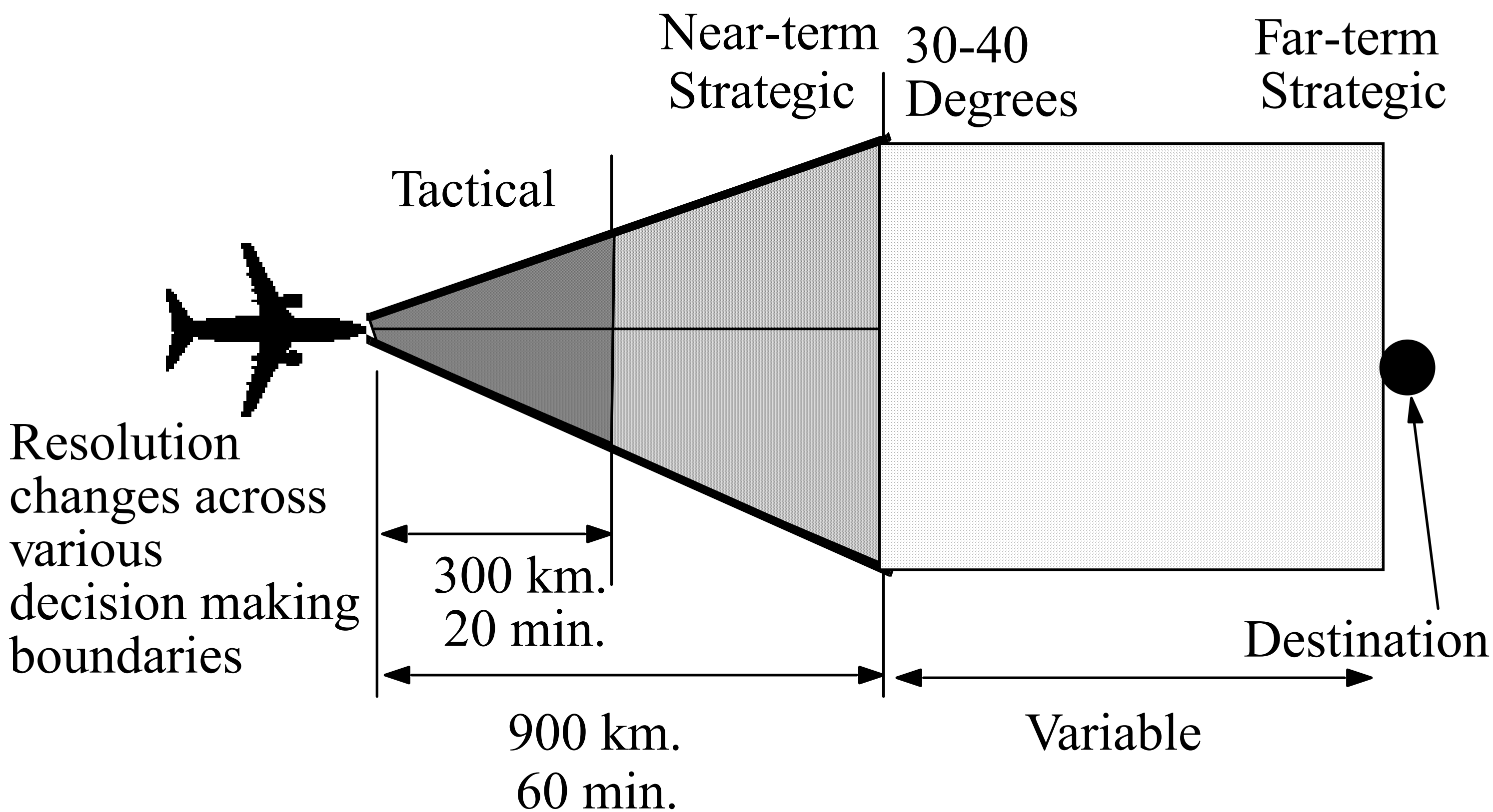
Three regions of interest: tactical, near-term strategic, far-term strategic
Fundamental Questions: How big is each region of interest? How many bytes req per sq mile? What is the refresh rate? What % of total dataset must be transmitted at each refresh point? What are typical aircraft densities when accessing this information?



Potential Applications

- **Air Traffic Management**
  - Strategic (traffic flow management)
  - Tactical (air traffic control)
- Aircraft Status Information
- **Weather in the Cockpit**
- **Aircraft as Weather Sensor**
- Airport and Terminal Area Status
- AOC Related Information
- General NAS Status

Lumped Air Traffic Flow Model

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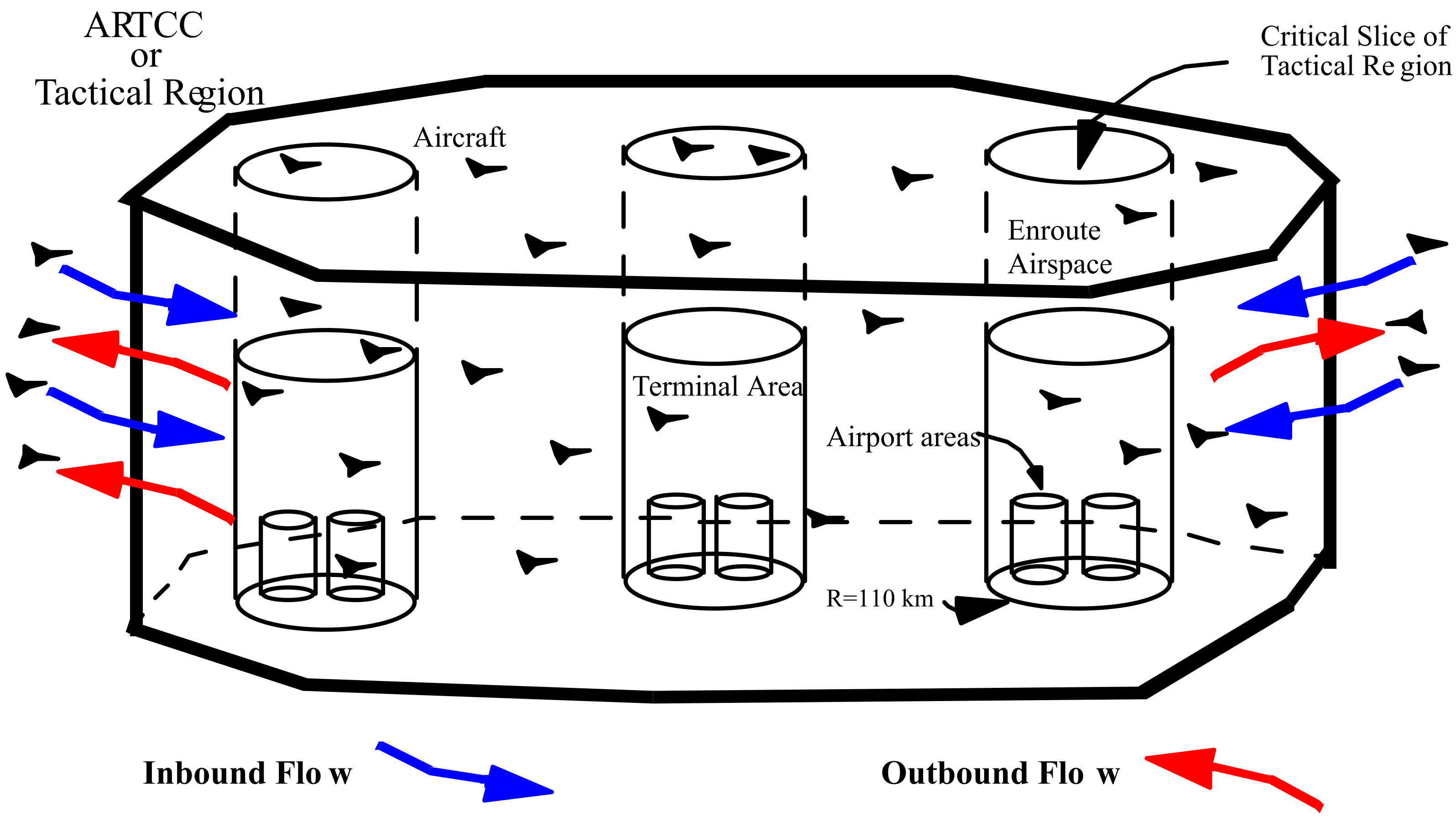
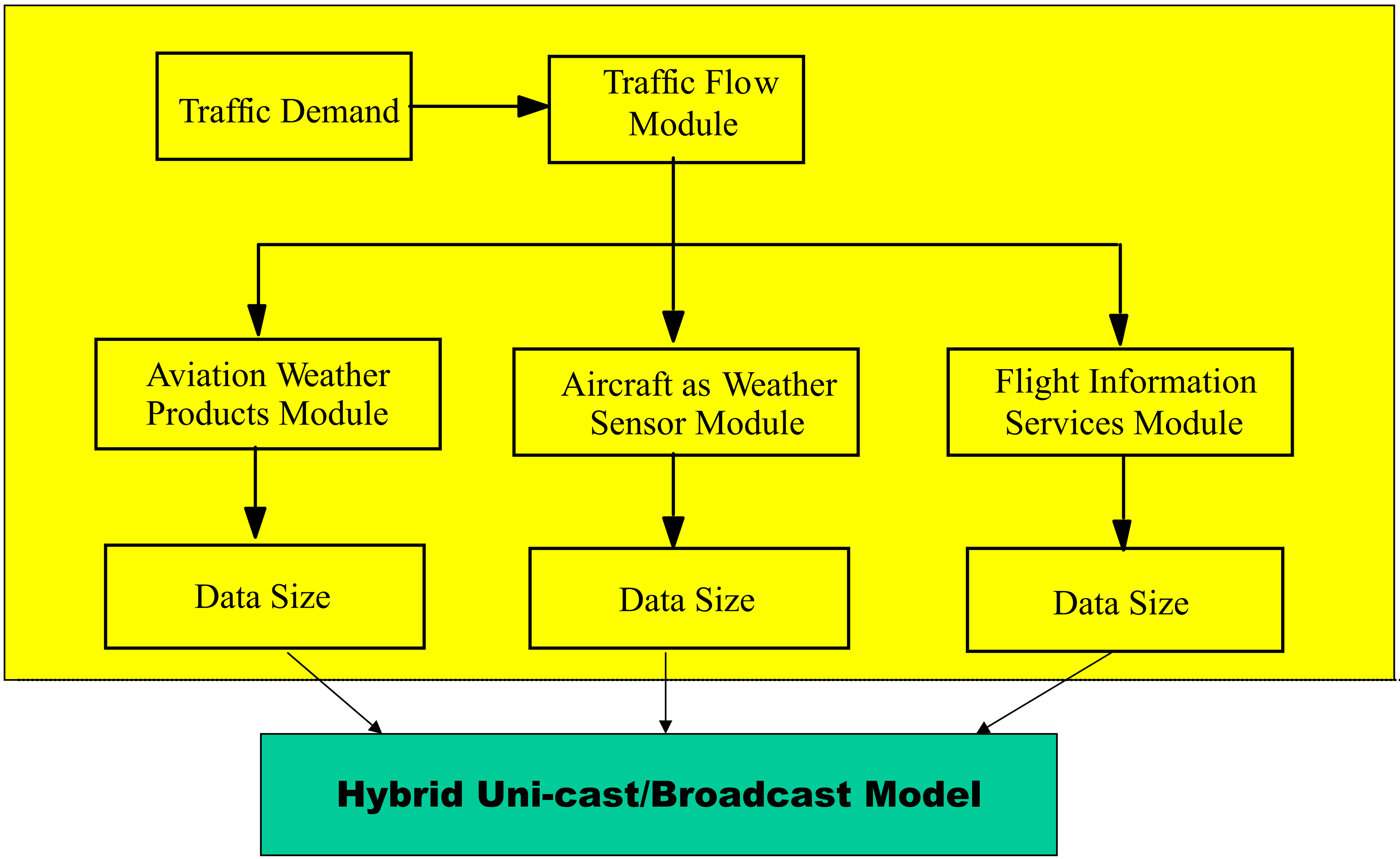


Dwell times are obtained using the VT Airspace Occupancy Model (AOM)

LATFM Organization



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Lumped Aircraft Traffic Flow Model
(Traffic Flow Analysis Panel)

Model Inputs

Region Size

Tactical Area
5.00 — 12.00
9.00 x 10^4

Near Strategic Area
5.000 — 9.000
7.200 x 10^5

Far Strategic Area
1.000 — 2.000
1.200 x 10^6

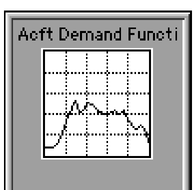
Initial Aircraft at Airports
600 — 2000
U 1200

Aircraft Regional Dwell Times

Mean Inbound Airport Dwell Time
0.00 — 40.00
15.00

Mean Inbound Terminal Dwell Time
10.00 — 45.00
U 34.00

Mean Inbound Enroute Dwell Time
10.00 — 60.00
45.00



SATS Switch

Input Demand Function

Traffic Forecast Model

Year of Analysis
1999 — 2025
U 2020

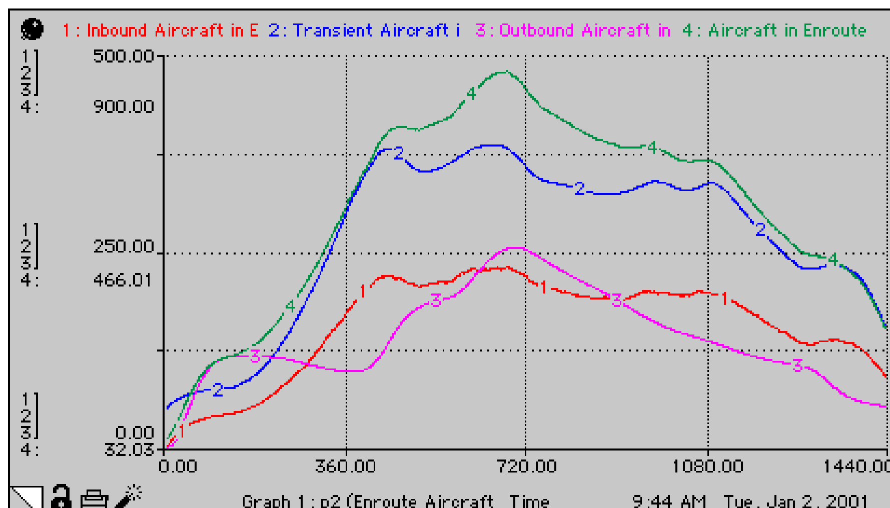
Scaling Factor for Enroute Flights
0.000 — 2.000
U 1.900

Model Traffic Flow Outputs

Peak Demand Factors	
Airport Area Peak Dema	0.45
Terminal Area Peak Dem	0.3
Enroute Peak Demand Fa	0.25

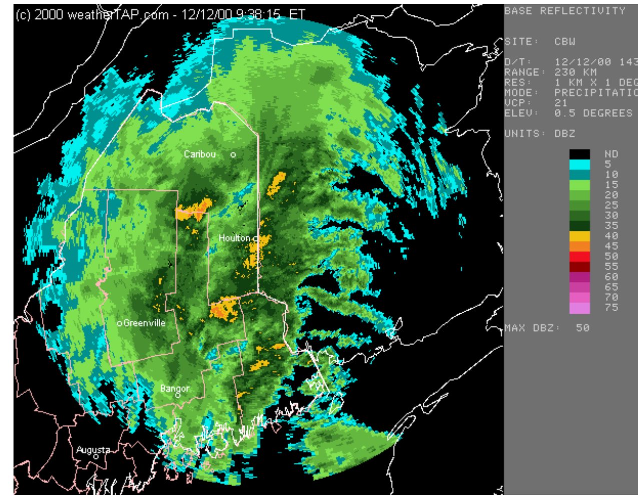
Aircraft in Airport	52.9
Aircraft in Terminal	105.0
Aircraft in Enroute	295.3

Aircraft Traffic Flow State Variables



Run Model	Traffic Flow Analysis	Aviation Weather Products	Aircraft as Weather Sensor	Flight Information Services	Back to Introduction

Weather Information Services



- Assumes improvements
- to existing ground-based radars
  - a factor of 4 in processing time
  - A factor of 3 in resolution
- Tactical domain (1 minute update for all cells in the weather map)
- Near-term Strategic (3 minute update)
- Far-term strategic (10 minute update)

Aircraft as Weather Sensor

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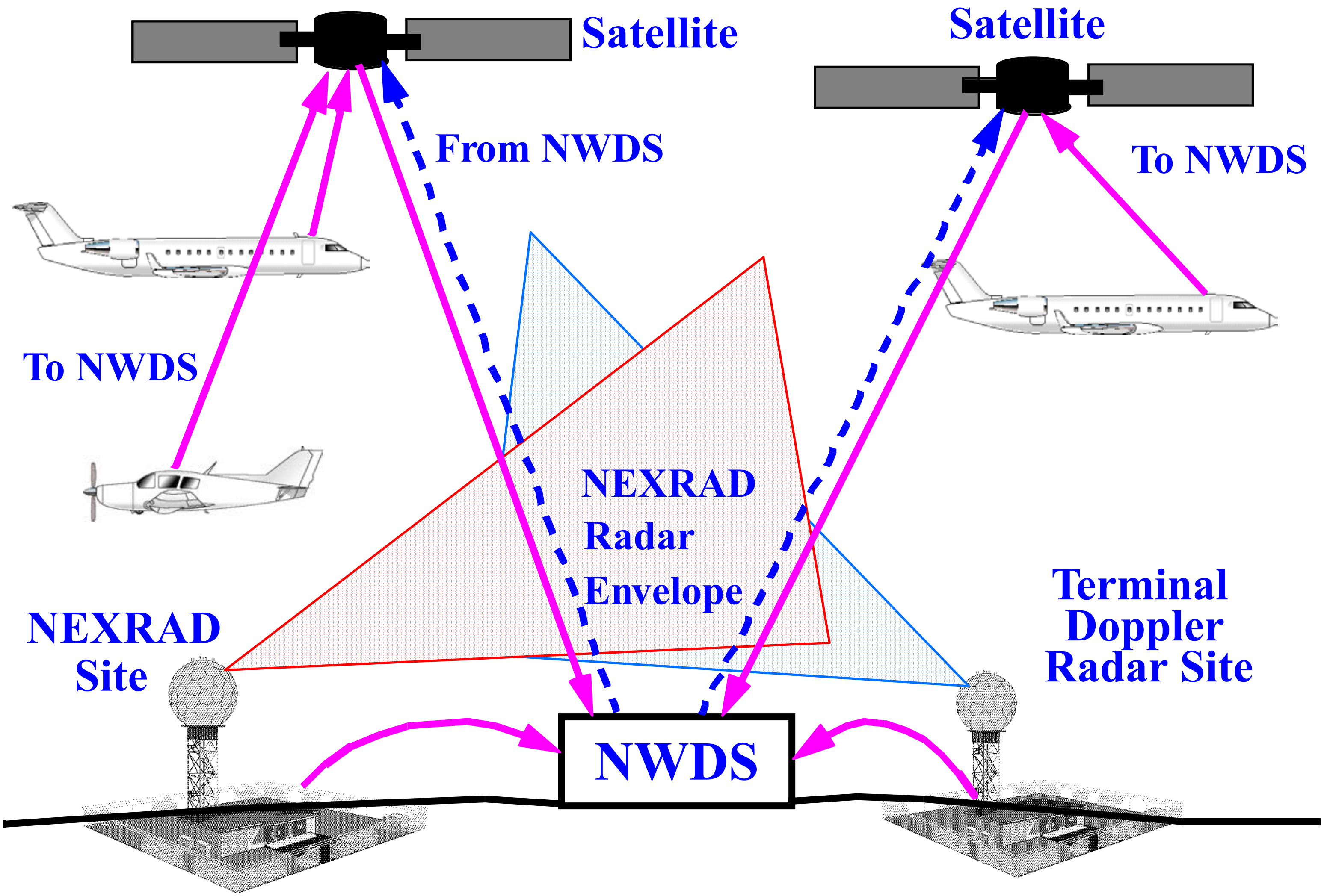
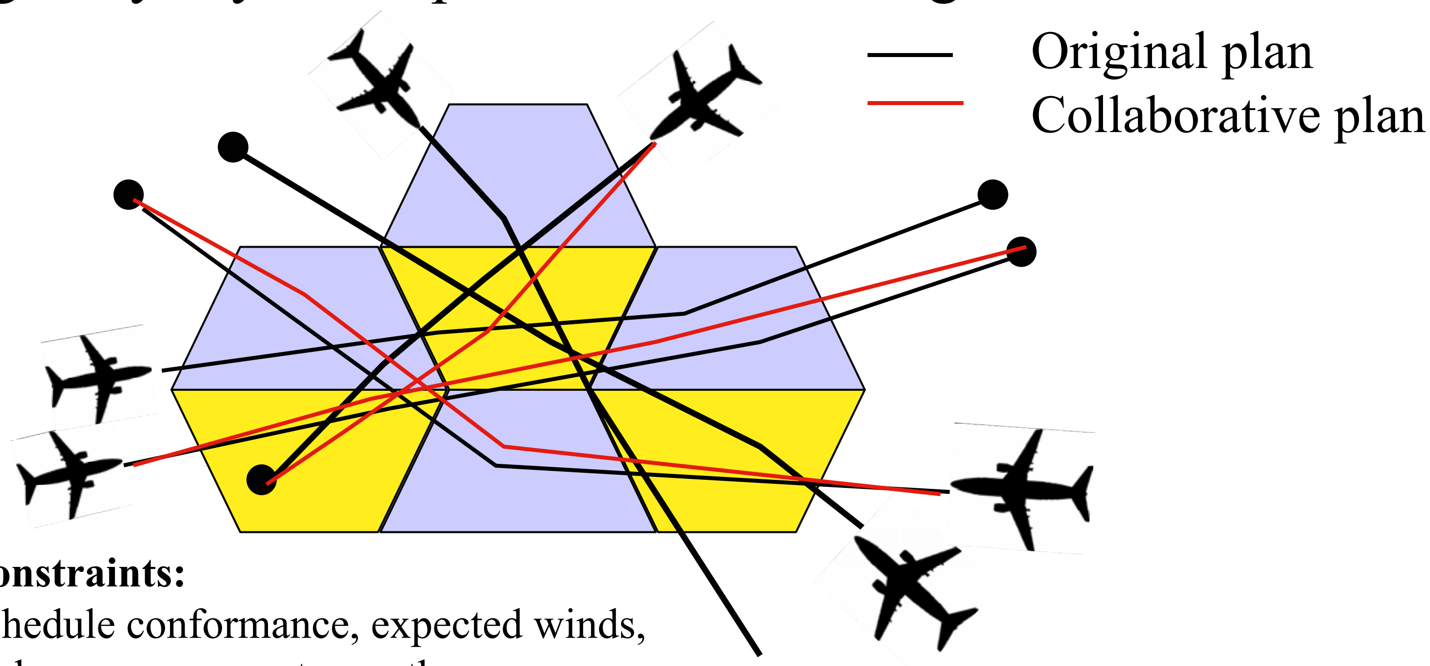


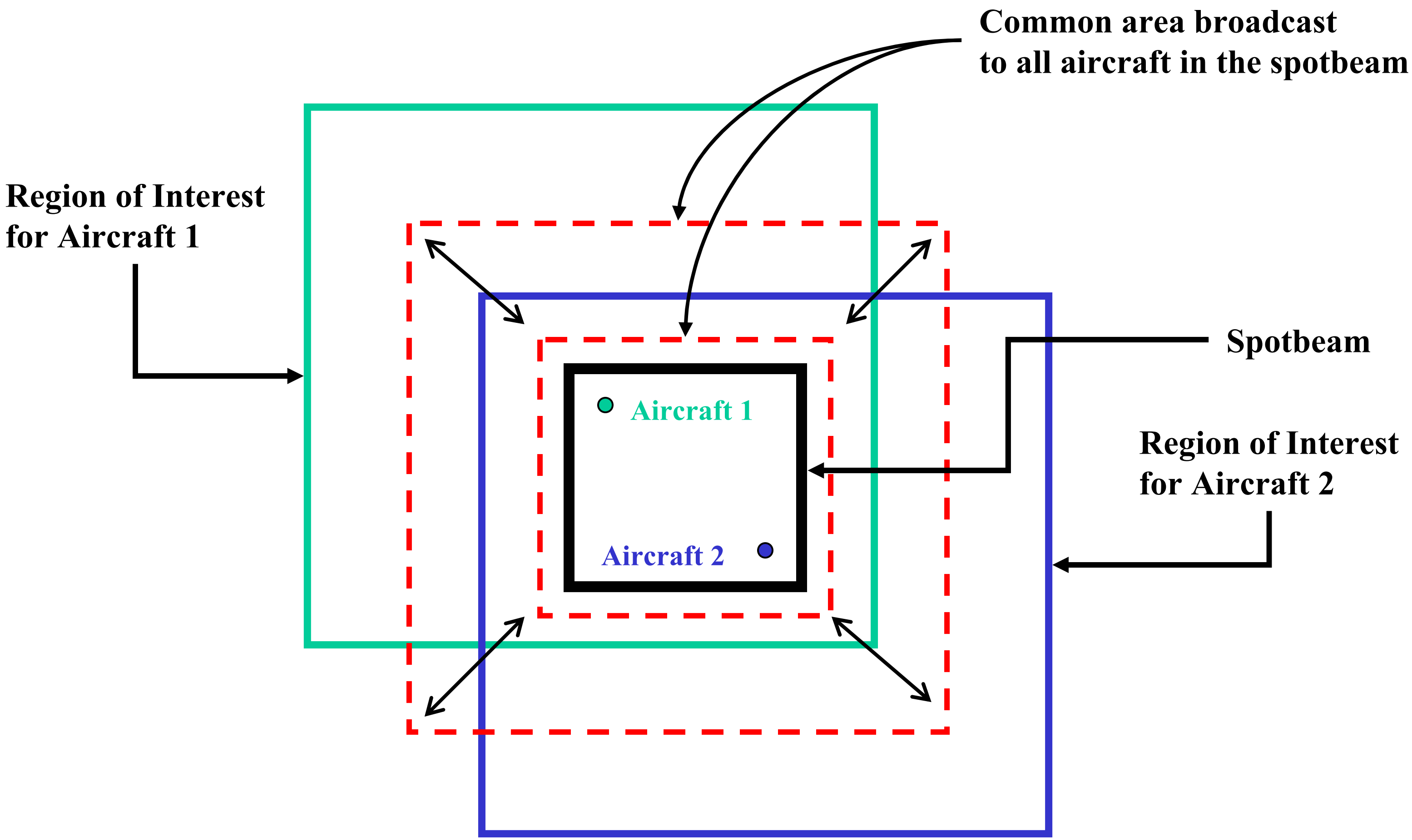
Traffic Information Services

- In 2020, the air traffic management systems will implement advanced forms of Collaborative Routing (CR)
- Tactically: Traffic avoidance
- Strategically: System optimal detour strategies



Constraints:
Schedule conformance, expected winds,
fuel reserves, enroute weather
aircraft weight, sector workload, cost index

Region of Interest of Different Aircraft in a Spot-beam



Communications Model

- Each aircraft has two types of channels:
  - Broadcast channel: Same information is transmitted to all aircraft.
  - Uni-cast channel: Information specific to an aircraft is transmitted.
- Each aircraft has two types of limited resources:
  - Bandwidth of the channel to the aircraft.
  - Processing power on-board aircraft.
- The weather map is delivered to the aircraft ready to be displayed on the cockpit display.
  - No further on-board processing is necessary if the exact map corresponding to the ROI of the aircraft is delivered.
  - If some unnecessary information is delivered, this information has to be filtered out causing a processing cost.

Communications Model

- On the broadcast channel of each spot-beam, a square area of certain size (BA) is broadcast to all aircraft residing in the spot-beam.
- Our objective is to determine the optimal size of the BA so that total bandwidth and processing cost is minimized.
  - We have to speculate on the unit processing cost in comparison to the bandwidth cost.
- As BA size increases, the amount of information transferred over the uni-cast channel decreases resulting in increased bandwidth efficiency, but also decreased processing efficiency.

Near-Term Strategic Weather Application over LEO satellite

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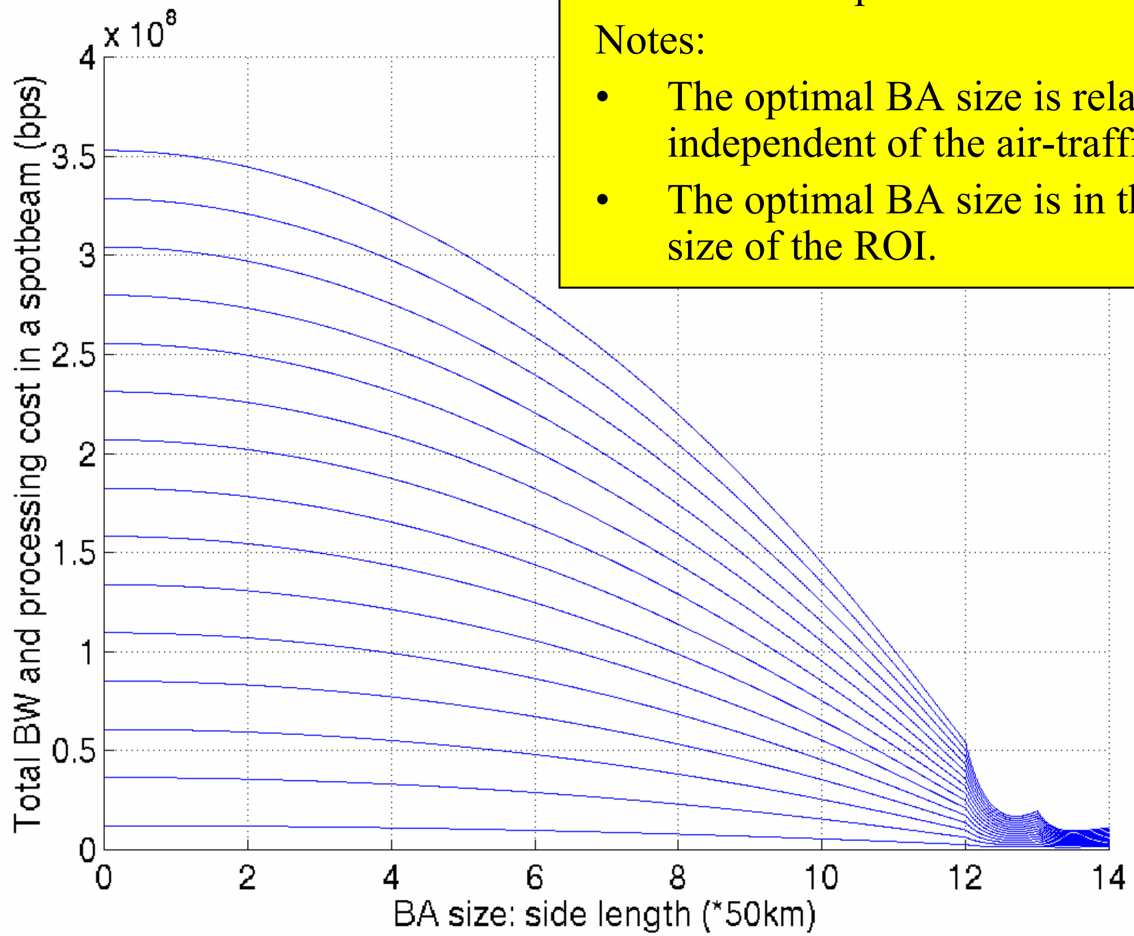
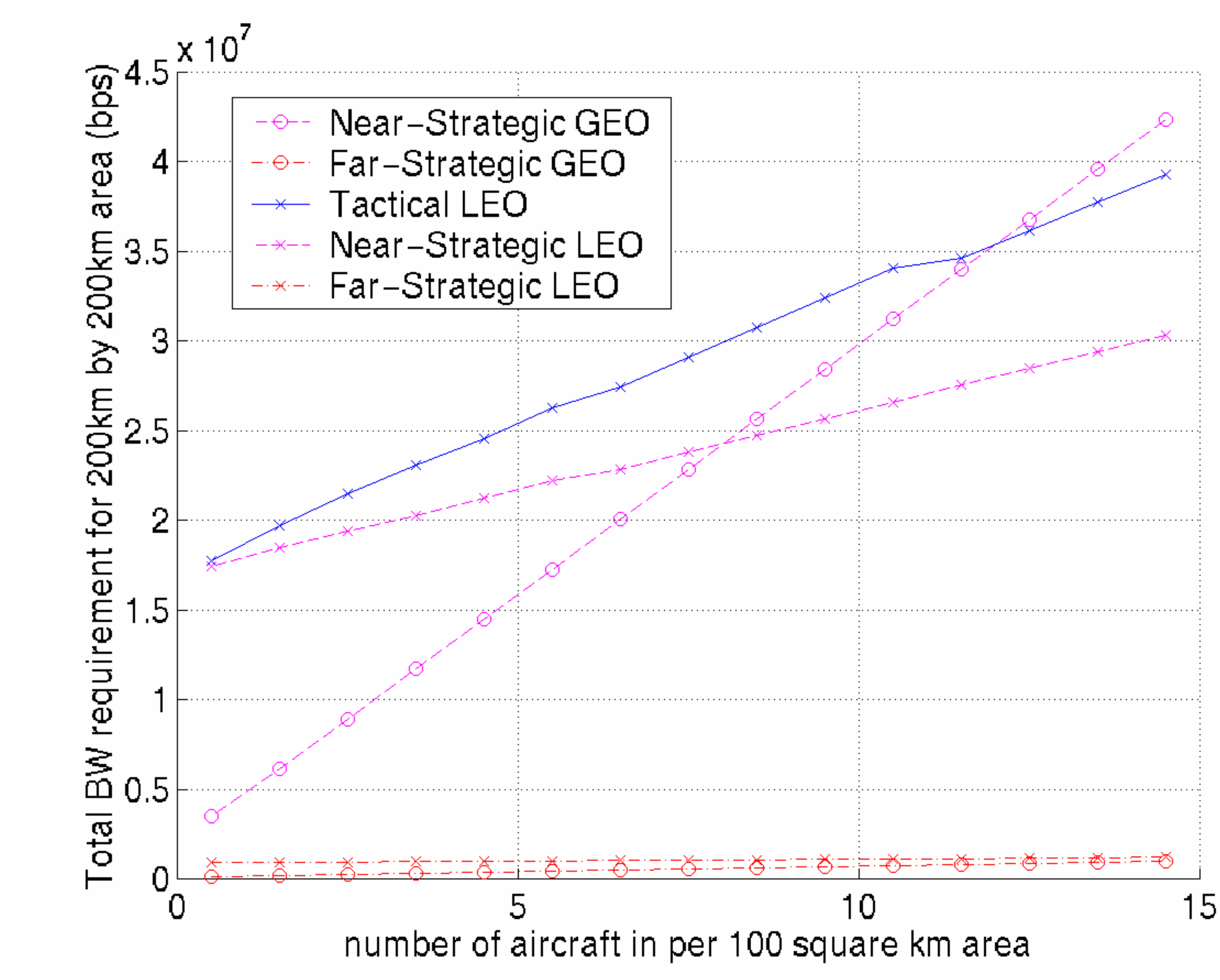
The air-traffic density is varied between 0.5 and 15 aircraft per 100 km^2.

Notes:

- The optimal BA size is relatively independent of the air-traffic density.
- The optimal BA size is in the vicinity of the size of the ROI.



Optimal BW Cost for Varying Air Traffic Densities



Interpretation of Results

- For the near-term strategic case, under low traffic density the hybrid GEO solution is better than the hybrid LEO solution:
  - To cover the same area as a GEO spot-beam, a LEO needs multiple spot-beams. Each spot-beam has a broadcast channel. The total bandwidth requirement due to the broadcast channel is higher for the LEO case. However, given that the LEO broadcast channels provide a more customized view, the uni-cast bandwidth requirement for LEOs is lower.
- For the far-term strategic case, hybrid GEO is always better than the hybrid LEO for reasonable densities.
- For the tactical case, LEO is always better than GEO.

Comparison of Broadcast and Hybrid Approaches over Unicast Transmission: Near-Strategic Weather

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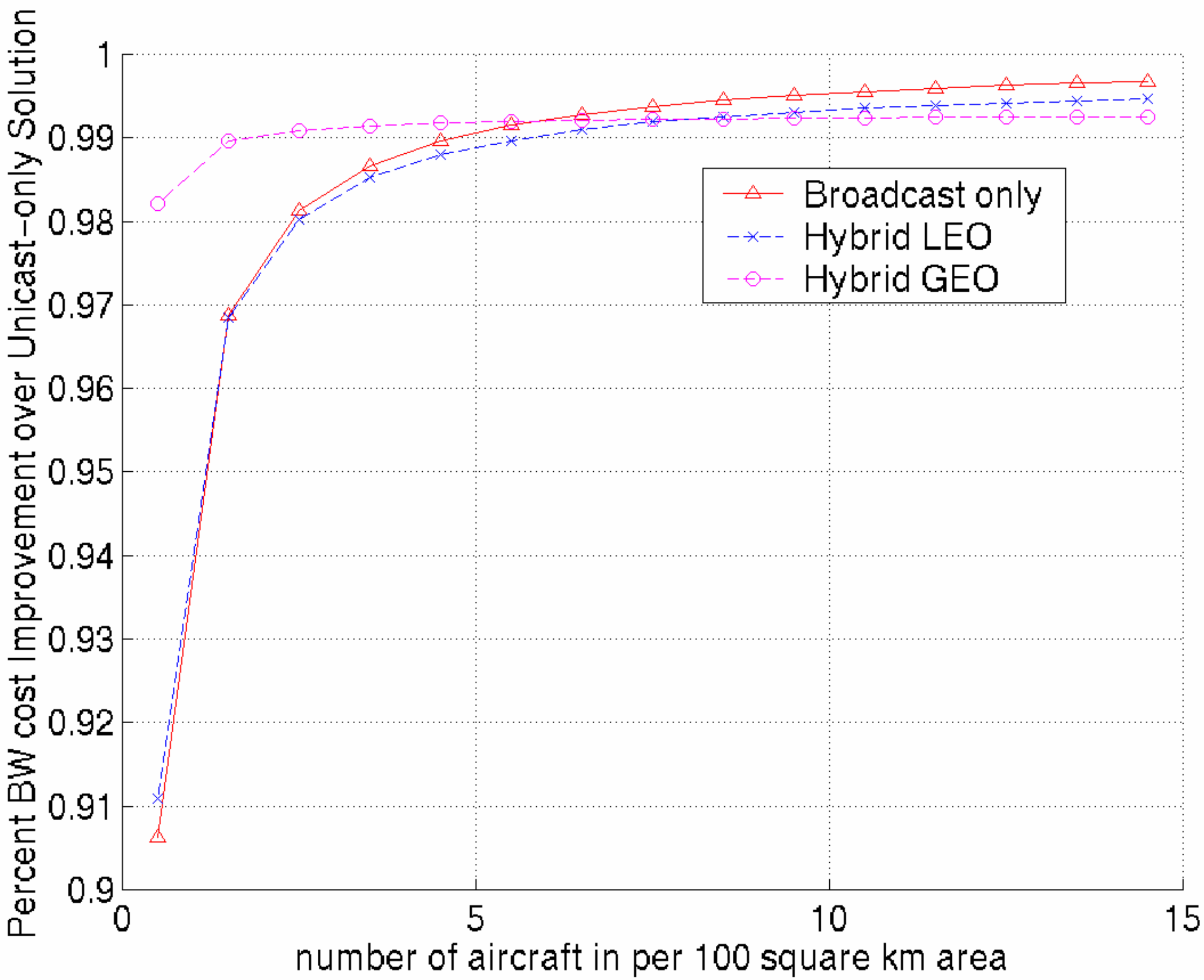

Bandwidth Requirements

	Tactical	Near-Strategic	Far-Strategic
Unicast BW requirement per aircraft	640 kbps	977 kbps	53 kbps
Unicast BW req. with differential trans. (30%)	192 kbps	293.1 kbps	15.9 kbps
Unicast BW req. when aircraft is a sensor with differential trans.	577 kbps	1.42 Mbps	49.63 kbps
Reduction factor in BW requirement by broadcast GEO at nominal density.	0.86	0.90	0.91
Reduction by hybrid GEO.		0.98	0.99
Reduction by hybrid LEO.	0.88	0.91	0.91

Conclusions

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- The growth in the demand function expected in the next two decades produced estimates of up to 1450 aircraft operations per hour in ROI
- Future bandwidth requirements are significant
- Broadcast capability can substantially reduce bandwidth
- The optimal area that leads to a minimum total bandwidth and processing costs is relatively independent from the air traffic density
- NGSS represent an attractive option:
  – GEO for far strategic and near strategic
  – LEO for tactical
  – Hybrid uni-cast/broadcast can provide the best solution